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An analysis of cogeneration system utilized as sustainable energy in the industrial sector in Taiwan

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Abstract

Taiwan is a high energy-importing nation with approximately 98% of our energy supplied by imported fuels in 2004. The energy conservation and/or energy efficiency improvement is becoming vital energy issues in the country. In this regard, cogeneration system or combined heat and power system used for the utilization of waste heat from energy and industrial sectors is thus becoming attractive due to the energy, economic and environmental policies for pursuing stable electricity supply, sustainable development and environmental pollution mitigation in Taiwan. The objective of this paper is to present an analysis of cogeneration system utilized as sustainable energy in the industrial sector in Taiwan. The description in the paper is thus summarized on an analysis of electricity supply/consumption and its sources from cogeneration system during the past two decades (1984–2004) and then centered on new/revised promotion legislation/regulations especially concerning cogeneration system in the measures of environmental protection and economic/financial incentives. Finally, we preliminarily present the results of environmental benefit analysis in the greenhouse gases reduction. Based on the data in 2004, it was found that the reduction benefits of carbon dioxide and nitrous oxide were estimated to achieve 3.488×10^7 and 650 metric tones, respectively.

Keywords: Cogeneration system; Electric power; Promotion regulation; Energy policy; Environmental benefit

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Contents

1. Introduction

All the energy we use is basically to satisfy human need and therefore contribute to human well-being because it plays a vital role in national economic development. The situation is particularly important to the area or country with limited primary energy resources. Taiwan, which is located in the southeastern rim of Asia and had the population of about 23,000 thousands by the end of 2004, is a high energy-importing nation with approximately 98% of our energy supplied by imported fuels in 2004 [1]. With the rapid industrialization in the past two decades (1984–2004), the country is now on the way to developed countries. Total energy consumption has increased significantly from 33.97 million kiloliters of oil equivalent (KLOE) in 1984 to 107.87 millions KLOE in 2004, which was an annually average growth rate of 5.94%. As a result, the increase in real gross national product (GNP, at 2001 prices) was on a parallel with the energy consumption from million NT$3,214,370 (≒ million US$100,000) in 1984 to million NT$10,726,908 (≒million US$320,000) in 2004. It was noted that 50% or more of total energy consumption in 2004 were used to generate electricity and as industrial stuffs in the industrial sector for the purpose of producing products. With respect to electricity generation, it grew from 52.2 T W h in 1984 to 218.4 T W h in 2004, an average annual increase of 7.42%. Of the electricity supply in 2004, the contribution of Taiwan Power Company (Taipower, one of government-owned enterprises) decreased to 64.3%, comprised 3.0% from hydro power, 43.2% (coal shared 28.4%, oil 5.2% and liquefied natural gas 9.6%) from thermal power and 18.1% from nuclear power. The remaining portion (35.7%) was generated from cogeneration systems (19.5%) and independent power plants (IPP, 16.2%). When classified by sector, energy and industrial sectors consumed 57.7% of total electricity supply in 2004, residential sector accounted for 19.2%, commercial sector amounted to 10.5% and other sectors occupied 12.6%. Based on the above-mentioned data, the manufacturing industry is the largest energy- and electricity-consumption sector. Consequently, the implementation for

energy-efficiency or energy saving improvement has became an important issue because of the cost saving and greenhouse gases (GHGs) emissions reduction.

In recent years, the environmental issues such as global warming and acid rain are consecutively arousing public concerns. In response to the Kyoto Protocol adopted in December 1997 and effective in February 2005, Taiwan convened two National Energy Conferences in May 1998 and June 2005, respectively. One of the most important conclusions is to increase the share of energy saving in the energy/industrial sectors because they accounted for around 87% of total GHGs emissions of Taiwan in 2000 [2]. Thus, the energy-efficiency improvement will be a major component of the national energy policy in order to cope with the actual needs of energy supply and to coordinate with the economic development in Taiwan [3]. One of the promotional measures for the conservation of energy and the implementation of energy efficiency in the power and industrial sectors shall be to install cogeneration systems further in the near future.

The energy utilization of waste heat from process industries (especially in energy-intensive industries such as steel, paper, chemicals, petroleum and cement) has received much attention since the energy crisis in the 1980s because it plays a vital role in the energy-efficiency improvement potentials [4]. Cogeneration, also known as combined heat and power (CHP), is the simultaneous production of electricity and heat in one single process for dual output streams so as to maximize its thermal efficiency of up to 90% or more. However, on an average of 35–55% of the energy potential contained in the fed fuel is converted into electricity in the conventional power system [5]. In other words, cogeneration uses both electricity and heat and therefore generates energy saving between 15% and 40% when compared with the separate production of electricity from conventional power stations and of heat from industrial boilers. In addition to the energy saving and cost saving, the benefits of cogeneration system are mainly from lower air pollutants emissions to the atmospheric environment, in particular carbon dioxide and nitrous oxide, the main GHGs [6].

Because of the increasing trend of crude oil prices, limited resources in fossil fuels and environmental concern in global warming, the objectives of this paper will present a comprehensive analysis of the regulatory measures for promoting cogeneration system and its potential environmental benefits in Taiwan. The main subjects covered in this paper were described in the following key elements:

- Current status of electricity supply/consumption and its sources from cogeneration system.
- Energy regulations and policies for promoting cogeneration system.
- Economic regulations and policies for financing cogeneration system.
- Environmental regulations and policies for encouraging and regulating cogeneration system.
- Environmental benefits from cogeneration system.

2. Current status of electricity supply/consumption and its sources from cogeneration system

2.1. Current status of electricity supply

It is well known that stable electricity supply plays a core role in economic development. Prior to the 1990s, Taipower, which is one of government-owned enterprises, was entrusted with development, generation, supply, transmission/distribution and marketing of electric

power in the Taiwan area. Under the government policy on the deregulation of the electric power sector and the energy saving in consideration of economic/environmental benefits, privately industrial plants from the energy-intensive industries (e.g. steel, paper and pulp, petrochemical and cement manufacturing) have been encouraged to install cogeneration system and to sell their surplus electricity to Taipower for its own distribution. In order to maintain a stable electricity supply, the central competent authority (i.e. Ministry of Economic Affairs, MOEA) has also promoted the opening of the electric power market to IPP in three stages during the years 1995–1999 [3].

As seen in Tables 1 and 2 [1], reliance on Taipower's electricity supply based on installed capacity or power generation was on the decreasing trend due to the nation's energy policy on efforts to diversify electric power sources and to raise the rational rate (i.e. 15–20%) of reserve capacity. On the other hand, however, the reliance on cogeneration system was on the increasing trend. With respect to the electricity supply in the past two decades (1984–2004), some notable points were further addressed as follows [3]:

- By the end of 2004, the total installed capacity of power plants was approximated to 42,000 MW, of which 65.8% was Taipower, 17.2% was IPP and 17.0% was cogeneration system. In contrast to the foregoing data, the total installed capacity of power plants in 1984 was only 13,159 MW, of which 98.4% was Taipower and 1.5% was cogeneration system.
- From the statistics of power generation, the electric power generation of all the power plants in 2004 totaled 218,363 GW h, of which 64.3% was Taipower, 16.2% was IPP and 19.5% was cogeneration system. In contrast to the foregoing data, the electric power generation of power plants in 1984 only amounted to 52,213 GW h, of which 98.6% was Taipower and 1.4% was cogeneration system.
- Total installed electricity capacity of Taipower was 27,589 MW in 2004, of which 16.3% was hydro power, 65.0% was thermal power (including 29.4% coal-fired, 12.9% oil-fired and 22.7% gas-fired) and 18.6% was nuclear power. However, total installed electricity capacity of Taipower in 1984 was only 12,960 MW, of which 11.4% was hydro power, 56.2% was thermal power (including 19.3% coal-fired and 36.9% oil-fired) and 32.4% was nuclear power. Based on the foregoing data, it showed that national reliance on nuclear energy in 1984 was significantly large in contrast with that of cogeneration system. In response to the environmental impact on air quality, the government has diversified its energy sources. Approximately 6300 MW (15.0%) of total installed electricity capacity in 2004 came from gas fuel, compared to 0 MW (0%) in 1984 and 672 MW (3.2%) in 1992.
- The power generation by Taipower in 2004 totaled 140,360 GWh, of which 4.7% was hydro power, 67.2% was thermal power (including 44.2% coal-fired, 8.1% oil-fired and 14.9% gas-fired) and 28.1% was nuclear power. By comparison, total power generation by Taipower in 1984 was about 51,470 GW h, of which 8.6% was hydro power, 43.6% was thermal power (including 24.5% coal-fired and 19.1% oil-fired) and 47.8% was nuclear power.

2.2. Current status of electricity consumption

According to the energy statistics by Bureau of Energy (BOE) under MOEA [1], the data on final electricity consumption by sectors in Taiwan and its main energy sources

Table 1
Installed capacity of various forms of energy in the past two decades (1984–2004) in Taiwan[a]

Sector	1984	1986	1989	1992	1995	1998	2001	2004
Taipower Co.[b]	12,960.0 (98.42%)	16,595.0 (98.82%)	16,594.0 (96.18%)	19,247.0 (92.52%)	21,898.0 (90.99%)	26,680.0 (89.99%)	27,391.6 (77.09%)	27,588.7 (65.76%)
Hydro power[c]	1480.0 (11.25%)	2564.0 (15.27%)	2563.0 (14.86%)	2577.0 (12.39%)	4183.0 (17.38%)	4422.0 (14.91%)	4422.0 (12.44%)	4501.0 (10.73%)
Thermal power	7287.0 (55.38%)	8887.0 (52.92%)	8887.0 (51.51%)	11,526.0 (55.40%)	12,571.0 (52.24%)	17,114.0 (57.73%)	17,825.6 (50.18%)	17,943.7 (42.77%)
Coal-fired	2505.0 (19.04%)	3955.0 (23.55%)	3750.0 (21.74%)	5825.0 (28.00%)	5900.0 (24.52%)	8100.0 (27.32%)	8100.0 (22.80%)	8100.0 (19.31%)
Oil-fired	4782.0 (36.34%)	4932.0 (29.38%)	5137.0 (29.77%)	5029.0 (24.17%)	5449.0 (22.64%)	5084.0 (17.15%)	3743.4 (10.54%)	3571.1 (8.51%)
LNG-fired	— (—)	— (—)	— (—)	672.0 (3.23%)	1222.0 (5.08%)	3930.0 (13.26%)	5982.2 (16.84%)	6272.6 (14.95%)
Nuclear power	4193.0 (31.86%)	5144.0 (30.63%)	5144.0 (29.81%)	5144.0 (24.73%)	5144.0 (21.37%)	5144.0 (17.35%)	5144.0 (14.47%)	5144.0 (12.26%)
IPP[d]	— (—)	— (—)	— (—)	— (—)	— (—)	— (—)	2700.0[d] (7.60%)	7228.8 (17.23%)
Cogeneration plant[e]	195.8[g] (1.49%)	195.8 (1.16%)	655.9 (3.80%)	1553.2 (7.47%)	2167.9 (9.01%)	2967.5 (10.01%)	5434.8 (15.30%)	7129.0 (16.99%)
Renewable power[f]	3.0[g] (0.02%)	3.0 (0.02%)	3.3 (0.02%)	3.3 (0.01%)	0.3 (0.00%)	— (—)	5.3 (0.01%)	9.1 (0.02%)
Total	13,158.8 (100.00%)	16,793.8 (100.00%)	17,253.2 (100.00%)	20,803.5 (100.00%)	24,066.2 (100.00%)	29,647.5 (100.00%)	35,531.7 (100.00%)	41,955.6 (100.00%)

[a] *Source*: [1]; unit: Megawatt (MW).
[b] Taipower Co. is a government-owned enterprise in Taiwan.
[c] Including the commissioned hydro power plants.
[d] The "IPP" denotes the abbreviation of independent power plants. The installed capacities (percentage) of IPP in the years 1999–2004 are 1650.0 (5.05%), 2250.0 (6.47%), 2700.0 (7.60%), 4608.8 (12.10%), 5758.8 (14.36%), and 7228.8 (17.23%) MW, respectively.
[e] Including the biomass-to-generation (bagasse, black liquor, and biogas) and waste-to-generation (municipal solid waste and waste tires) capacity.
[f] Including the geothermal, solar and wind power capacity.
[g] Estimated values.

(i.e. coal-, petroleum- or natural gas-fuel) were listed in Tables 3 and 4, respectively. Some important features were further analyzed as follows:

- Total electricity consumption in 2004 amounted to about 206,000 GW h, an increase of 70.4% since 1995 and 320.9% since 1984, of which 50.5% was used in the industrial sector, 19.2% for residential use, 10.5% for commercial use, 7.2% for energy use, 1.9% for agricultural and transportation uses and 10.7% for other uses.
- The increasing trend was in parallel with the growth rate of real gross national product (GNP, at 2001 prices) [1]. In the past two decades (1984–2004), average growth of GNP was about 6.71%, while the annual growth of electricity consumption was 7.42% at the same period.
- In response to the crude oil price on the increasing trend in the past decade, private enterprises and government-owned enterprises (i.e. Taipower and Chinese Petroleum Corporation) have diversified their energy sources. From the data in Table 4, it is clear

Table 2
Power generation of various forms of energy in the past two decades (1984–2004) in Taiwan[a]

Sector	1984	1986	1989	1992	1995	1998	2001	2004
Taipower Co.[b]	51,472.8 (98.58%)	61,585.7 (98.80%)	80,178.4 (95.39%)	96,727.5 (91.66%)	120,256.5 (90.34%)	145,218.1 (89.99%)	141,736.5 (75.18%)	140,359.8 (64.28%)
Hydro power[c]	4429.2 (8.48%)	7418.8 (11.90%)	6682.3 (7.95%)	8351.2 (7.91%)	8879.4 (6.67%)	10,607.9 (6.50%)	9169.4 (4.86%)	6529.6 (2.99%)
Thermal power	22,454.7 (43.01%)	27,226.1 (43.68%)	45,220.0 (53.80%)	54,531.8 (51.68%)	76,061.5 (57.14%)	97,785.7 (59.93%)	97,080.7 (51.50%)	94,340.1 (43.20%)
Coal-fired	12,634.9 (24.20%)	19,743.1 (31.67%)	23,605.4 (28.08%)	31,121.9 (29.49%)	41,196.7 (30.95%)	57,702.6 (35.36%)	58,133.4 (30.84%)	61,979.1 (28.38%)
Oil-fired	9819.7 (18.81%)	7483.1 (12.01%)	21,614.6 (25.72%)	20,619.5 (19.54%)	29,316.8 (22.02%)	26,153.5 (16.03%)	21,035.4 (11.16%)	11,383.4 (5.21%)
LNG-fired	— (—)	— (—)	— (—)	2790.4 (2.65%)	5548.0 (4.17%)	13,929.6 (8.54%)	17,912.0 (9.50%)	20,977.6 (9.61%)
Nuclear power	24,588.9 (47.09%)	26,940.8 (43.22%)	28,276.1 (33.64%)	33,844.5 (32.07%)	35,315.6 (26.53%)	36,824.5 (22.56%)	35,486.4 (18.82%)	39,490.1 (18.09%)
IPP[d]	— (—)	— (—)	— (—)	— (—)	— (—)	— (—)	14,334.7d (7.60%)	35,403.1 (16.21%)
Cogeneration plant[e]	737.1 (1.41%)	739.1 (1.19%)	3872.8 (4.61%)	8798.4 (8.34%)	12,860.2 (9.66%)	17,968.2 (11.01%)	32,447.9 (17.21%)	42,579.7 (19.51%)
Renewable power[f]	3.5 (0.01%)	4.5 (0.01%)	3.3 (0.00%)	1.9 (0.00%)	— (—)	— (—)	12.5 (0.01%)	20.6 (0.01%)
Total (Gross generation)	52,213.4 (100.00%)	62,329.3 (100.00%)	84,054.6 (100.00%)	105,527.9 (100.00%)	133,116.7 (100.00%)	163,186.4 (100.00%)	188,531.7 (100.00%)	218,363.2 (100.00%)

[a] *Source*: [1]; unit: Gigawatt-hour (GW h).
[b] Taipower Co. is a government-owned enterprise in Taiwan.
[c] Including the commissioned hydro power plants.
[d] The "IPP" denotes the abbreviation of independent power plants. The installed capacities (percentage) of IPP in the years 1999-2004 are 3413.1 (2.01%), 9371.8 (5.07%), 14,334.7 (7.60%), 22,477.1 (11.32%), 28,516.1 (13.64%) and 35,403.1 (16.21%) MW, respectively.
[e] Including the biomass-to-generation (bagasse, black liquor, and biogas) and waste-to-generation (municipal solid waste and waste tires) capacity.
[f] Including the geothermal, solar and wind power capacity.

that most of coals and liquefied natural gas (LNG) (i.e. 75.3% and 87.7%, respectively) were used for the power generation and cogeneration in contrast with that (i.e. 9.3%) of petroleum in 2004. By comparison, the portions of coal, LNG and petroleum used for the power generation and cogeneration in 1992 were 58.3%, 50.3% and 18.45%, respectively.

2.3. *Current status of electricity from cogeneration system*

To promote the cogeneration system for the purpose of upgrading efficient utilization of energy in the industrial sector, the central competent authority (i.e. MOEA) issued and implemented a regulation ("Promoting Measures for Cogeneration System") on July 15, 1988. Thereafter, total installed capacity and power generation of cogeneration system were both on the increasing trend mainly due to the rates for surplus electricity purchased by Taipower and the tax benefits and financial incentives provided (described in Sections 3

Table 3
Final electricity consumption by sectors in the past two decades (1984–2004) in Taiwan[a]

Sector	1984	1986	1989	1992	1995	1998	2001	2004
Energy	3685.8 (7.53%)	4610.0 (7.99%)	5770.6 (7.50%)	6694.1 (6.88%)	8174.8 (6.76%)	10,059.4 (6.90%)	13,125.0 (7.46%)	14,848.6 (7.20%)
Transportation	360.6 (0.74%)	368.0 (0.64%)	379.8 (0.49%)	436.9 (0.45%)	466.4 (0.38%)	790.5 (0.54%)	1116.0 (0.63%)	1311.7 (0.64%)
Industrial	27,574.1 (56.31%)	32,190.0 (55.82%)	41,153.9 (53.45%)	50,076.8 (51.43%)	58,574.7 (48.42%)	70,767.8 (48.57%)	85,754.6 (48.75%)	104,124.2 (50.52%)
Agricultural	1011.8 (2.07%)	1353.0 (2.35%)	1745.9 (2.27%)	1669.5 (1.71%)	2042.3 (1.69%)	2064.0 (1.42%)	2229.0 (1.27%)	2510.7 (1.22%)
Residential	9414.5 (19.22%)	10,778.9 (18.69%)	14,824.5 (19.25%)	19,283.5 (19.80%)	25,329.2 (20.94%)	29,169.3 (20.02%)	35,656.1 (20.27%)	39,587.9 (19.21%)
Commercial	2599.1 (5.31%)	3069.5 (5.32%)	5674.4 (7.37%)	9163.9 (9.41%)	12,667.4 (10.47%)	16,775.3 (11.51%)	19,062.1 (10.83%)	21,683.5 (10.52%)
Others	4321.6 (8.82%)	5299.6 (9.19%)	7447.9 (9.67%)	10,050.7 (10.32%)	13,713.2 (11.34%)	16,087.1 (11.04%)	18,974.2 (10.79%)	22,034.1 (10.69%)
Total	48,967.5 (100.00%)	57,669.1 (100.00%)	76,996.9 (100.00%)	97,375.4 (100.00%)	120,968.0 (100.00%)	145,713.4 (100.00%)	175,917.1 (100.00%)	206,100.7 (100.00%)

[a] *Source*: [1]; unit: Gigawatt-hour (GW h).

and 4), as seen in Figs. 1 and 2. It was noted that the fuels fed in all installed cogeneration systems approximately included coal of 67%, oil of 17%, wastes of 11%, natural gas of 4% and other sources of 1% [7], indicating that the energy cost was still a determining factor in the purchase of fuel in spite of its higher air pollution emissions.

By the end of 2005, all cogeneration systems in the Taiwan area were listed in Table 5 [8]. Some important features in Table 5 and Fig. 1 are pointed out as follows:

- Total number of cogeneration systems was 94, of which 27 were from public services (including municipal solid waste incineration plants [9] and sanitary landfills [10]), 12 were from synthetic fiber plants, 11 were from petrochemical plants, 9 were from paper and pulp plants, 9 were from food plants (including 5 sugar refineries, which utilize their agrowaste bagasses as auxiliary fuel for generating steam and electricity [11]), 7 were from plastics plants, 5 were from textile plants, 4 were from oil and oil refining plants and 10 were other plants. Among them, 63 qualified cogeneration plants have contracted with Taipower (government-owned enterprise).
- Total installed capacity of cogeneration systems amounted to 7046 MW, of which 3156 MW (44.8%) from petrochemical plants, 886 MW (12.6%) from synthetic fiber plants, 812 MW (11.5%) were from plastics plants, 593 MW (8.4%) were from public services, 505 MW (7.2%) were oil and oil refining plants, 469 MW (6.7%) were from iron and steel plant and 675 MW (8.8%) were from other plants. According to the above-mentioned data, it is clear that the five largest energy-consuming industrial sectors (i.e. steel, petroleum, paper and board, cement and chemicals) have installed cogeneration system for energy saving because they are responsible for most of the industrial energy consumption, which accounted for 50.5% of the final electricity consumption in 2004 (as seen in Table 3).
- In the past two decades (1984–2004), annually average growth of total installed capacity from cogeneration system was about 22.5% according to the data of Table 2 in 1984

Table 4
Statistics of energy consumption by various forms of energy used for the power generation and cogeneration in the past two decades (1984–2004) in Taiwan[a]

Energy form	1984	1986	1989	1992	1995	1998	2001	2004
Coal (unit: 10^6 kg)	10,350.4	13,475.8	17,883.0	22,108.3	26,447.1	36,864.7	47,846.7	57,135.0
Energy transformation	7246.7	10,029.8	13,586.6	14,102.5	20,631.8	30,600.3	40,335.9	49,022.3
	(70.01%)	(74.43%)	(75.97%)	(75.91%)	(78.01%)	(83.01%)	(84.30%)	(85.80%)
Power generation and cogeneration	4786.9	7258.7	9189.5	10,065.1	16,452.4	24,589.6	34,629.7	43,028.8
	(46.25%)	(53.87%)	(51.38%)	(58.83%)	(62.21%)	(66.70%)	(72.38%)	(75.31%)
Coke	2459.8	2771.1	4397.0	4037.4	4179.4	6010.7	5706.2	5993.6
	(23.76%)	(20.56%)	(24.59%)	(17.08%)	(15.80%)	(16.31%)	(11.92%)	(10.49%)
Final consumption[b]	3103.7	3446.0	4296.5	5326.4	5815.2	6264.4	7510.8	8112.7
	(29.99%)	(25.57%)	(24.03%)	(24.09%)	(21.99%)	(16.99%)	(15.70%)	(14.20%)
Petroleum (unit: 10^3 KLOE)	18,754.9	20,696.0	27,593.3	29,935.3	36,786.9	38,807.8	42,652.1	46,492.8
Power generation and cogeneration	2424.0	1876.7	5596.3	5507.7	7811.7	7173.0	5955.0	4303.0
	(12.92%)	(9.07%)	(20.28%)	(18.40%)	(21.23%)	(18.48%)	(13.96%)	(9.25%)
Energy use	15,847.1	18,265.6	21,030.0	23,269.7	27,755.0	29,688.3	35,049.8	40,506.3
	(84.50%)	(88.25%)	(76.21%)	(77.73%)	(75.45%)	(76.50%)	(82.18%)	(87.13%)
Non-energy uses[c]	483.8	553.8	967.1	1157.9	1220.2	1946.6	1647.3	1683.5
	(2.58%)	(2.68%)	(3.51%)	(3.87%)	(3.32%)	(5.02%)	(3.86%)	(3.62%)
LNG (unit: 10^6 m^3)	—	—	—	1521.1	2378.8	4283.3	5476.3	8030.1
Power generation and cogeneration	—	—	—	765.0	1420.0	3228.1	4569.2	7040.8
	(—)	(—)	(—)	(50.29%)	(59.70%)	(75.36%)	(83.44%)	(87.68%)
Energy and industrial				732.8	912.0	990.6	824.3	818.9
				(48.17%)	(38.34%)	(23.13%)	(15.05%)	(10.20%)
Others	—	—	—	23.3	46.8	64.6	82.8	170.4
	(—)	(—)	(—)	(1.54%)	(1.96%)	(1.51%)	(1.51%)	(2.12%)
Natural gas (unit: 10^6 m^3)[d]	1266.1	1021.2	1151.3	1505.1	1692.9	1676.9	1426.0	1349.2
Power generation and cogeneration	—	—	8.0	6.7	7.2	6.9	7.4	5.7
	(—)	(—)	(0.70%)	(0.44%)	(0.43%)	(0.41%)	(0.52%)	(0.42%)
Industrial	769.5	468.3	484.9	760.6	872.7	818.1	476.5	367.7
	(60.78%)	(45.85%)	(42.11%)	(50.54%)	(51.55%)	(48.78%)	(33.41%)	(27.26%)
Residential	402.7	457.2	546.9	614.5	676.2	714.1	751.2	764.7
	(31.81%)	(44.77%)	(47.51%)	(40.83%)	(39.94%)	(42.59%)	(52.68%)	(56.67%)
Commercial	82.0	82.4	96.8	105.6	118.2	121.3	162.7	182.2
	(6.48%)	(8.07%)	(8.41%)	(7.02%)	(6.98%)	(7.23%)	(11.41%)	(13.50%)
Others	11.8	13.4	14.7	17.7	18.6	16.5	28.2	29.1
	(0.93%)	(1.31%)	(1.27%)	(1.17%)	(1.10%)	(0.99%)	(1.97%)	(2.15%)

[a] *Source*: [1].
[b] Including energy, transportation, industrial, agricultural, residential, commercial and other sectors, and non-energy use.
[c] Including energy, transportation, industrial, agricultural, residential, commercial and other sectors.
[d] The energy is totally from domestic production.

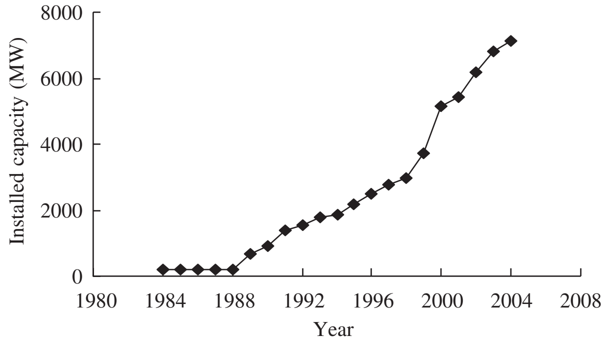


Fig. 1. Annual installed capacity of cogeneration systems in Taiwan during the period of 1984–2004.

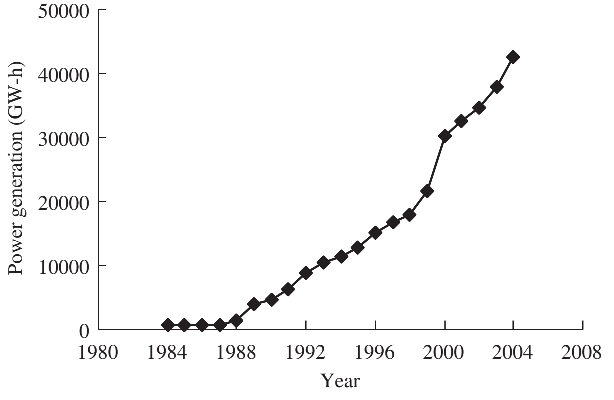


Fig. 2. Annual power generation of cogeneration systems in Taiwan during the period of 1984–2004.

and 2004. Obviously, the annual growth rate was larger than that (i.e. 7.4%) of total electricity supply at the same period based on the data in Table 2.

Based on the substantial reduction of GHGs emissions from the utilization of cogeneration system, the current government policies (described in Sections 3 and 4) for the promotion of the energy-saving measure will expect a progressive increase in the near future. According to the "White Book of Energy Policy" issued by the central competent authority (i.e. MOEA) at the end of 2004 [12], the projections of total installed capacity from cogeneration systems will sum up to 800 and 1000 MW in 2010 and 2020, respectively.

3. Energy regulations and policies for promoting cogeneration system

3.1. Energy Management Law

In response to the energy crisis in the 1970s, Taiwan government first promulgated the Energy Management Law (EML) in August 1980, which was thereafter revised in January

Table 5
Updated statistics of installed capacity of qualified cogeneration systems in Taiwan[a]

Industrial classification	No. of cogeneration plant	Installed capacity (kW)	Percentage (%)
Food	9[b]	68,850	0.98
Synthetic fiber	12	886,051	12.57
Textile	5	55,880	0.79
Paper and pulp	9	230,861	3.28
Petrochemical	11	3,156,263	44.79
Plastics	7	811,633	11.52
Basic chemical	3	33,300	0.47
Oil and oil refining	4	505,000	7.17
Cement	1	25,100	0.36
Iron and steel	1	468,700	6.65
Gas fuel supply	1	500	0.01
Cogeneration	2	116,400	1.65
Public service	27[c]	593,220	8.42
Electronic	2	94,700	1.34
Total	94[d]	7,046,458	100

[a]*Source*: [8]; The statistical data was updated on December 26, 2005.

[b]Including 5 sugar mills (Taiwan Sugar Company, one of government-owned enterprises) of waste (i.e. bagasse)-to-generation [11].

[c]Including 22 MSW-to-generation plants [9], and 5 biogas-to-generation plants [10].

[d]Among them, 63 qualified cogeneration plants have contracted with Taiwan Power Company (government-owned enterprise). Total guaranteed capacity at the peak of selling electricity is 2.58 millions kW.

1992, April 2000 and January 2002, respectively [13]. The principal purpose of the Law is to aim at rational and efficient utilization of energy, which is defined as one of petroleum, coal, natural gas, nuclear fuel, electricity energy or other authorized forms. According to the newly revised EML, important features concerning the aspects of cogeneration are stipulated in Article 10, which was summarized as follows:

1. The energy user, which generates the amount of steam set up by the central competent authority (i.e. MOEA), should install the cogeneration system.
2. The energy user, which meets the levels of effective thermal ratios and total thermal efficiencies set up by the central competent authority in its cogeneration system, may ask the local vertical integrated utilities (e.g. Taipower) to purchase its excess electricity and supply backup electricity needed for its system maintenance or at the time of system breakdown.
3. The central competent authority shall stipulate an implementation regulation regarding the rates for the purchase of excess electricity, the levels and verification of effective thermal ratios and total thermal efficiencies described in the foregoing clause, as well as the tie-in between the systems of the energy user and the vertical integrated utilities, the method of purchasing electrical energy, the rates for electricity and backup electricity purchased and the duration of the obligation to purchase excess electricity by the vertical integrated utilities.

Under the authorization of the Law, the MOEA has promulgated the regulations (i.e. "*Measures for Implementing the Cogeneration system*") since September 2002. Recently,

this regulation was further amended in March 2006. According to the Provision 5 of the regulation, the qualified cogeneration system is defined as referring to the registered energy user and its levels of effective thermal ratio [= effective heat output ÷ (effective heat output + effective electricity output)] ≧20% and total thermal efficiency [= (effective heat output + effective electricity output) ÷ heating value of fuel) ≧52% or the registered system specified in treating wastes. However, the regulation shall be temporarily effective in the next two years (up to December 31, 2007) prior to the pass of the Electricity Act Amendment aimed at the liberalization of electric sector in Taiwan.

3.2. Electricity Act

In order to exploit national energy power, regulate electricity supply, develop electricity enterprise management and maintain rational electricity price, the Electricity Act was first passed and promulgated in 1947 and thereafter revised in May 1965, April 2002, June 2002 and January 2005, respectively. It was noted that the future electricity market of Taiwan will be operated under the deregulation because the trend toward liberalization, internationalization and privatization in the electricity sector is inevitable on the way to developed country. Therefore, the Act will be further amended to aim at respecting electricity market mechanisms, avoiding unnecessary intervention and discretion by regulatory institutions and individuals, accelerating fair and open competition in the electricity market and upgrading operation efficiency in the energy-related enterprises [14]. It is clear that the power generated from the cogeneration systems in the industrial sectors can be sold to the energy users in the same industrial parks based on the electricity market price [15], not the current framework decided by the government-owned enterprise (i.e. Taipower).

4. Economic regulations and policies for financing cogeneration system

The implementation of cogeneration system for electricity generation often requires substantial investment by enterprises. In order to encourage industries to participate in the energy saving and new/clean energy, the central government now offers some tax benefits and financial incentives, which include tax deduction for investment, accelerated depreciation, tariff exemption and low interest loans, under the authorization of Statute for Upgrading Industries (SUI), which was originally promulgated and became effective in December 1990 and was recently revised in February 2005. According to the SUI, important features concerning the aspects of installing cogeneration system were briefly described as follows [16]:

1. To provide the financial incentives for any of the listed purposes (e.g. energy saving), service life of instruments and equipment purchased by a company may be accelerated to two years (Article 5).
2. To meet the requirement for industrial upgrading, an enterprise may credit 5–20% of the amount of fund disbursed for any of the listed purposes (e.g. the fund invested in the equipment or technology used for energy saving) against the amount of profit-seeking enterprise income tax payable for the then current year (Article 6).
3. The Executive Yuan (Cabinet) shall establish a development fund for low interest loans and make use of such development fund for the listed purposes (e.g. energy saving, greenhouse gases mitigation) (Article 21).

Under the authorization of Article 6 of SUI, the regulation, known as "Regulation of Tax Deduction for Investment in the Procurement of Equipments and/or Technologies by Energy saving or emerging/Clean Energy Organizations", has first been promulgated by the Ministry of Finance (MOF) in July 1997 and recently revised in March 2006. These specified organizations shall be granted credits on the profit-seeking enterprise income tax for the current year if they use these equipments (e.g. cogeneration system) and/or technologies by themselves according to the following percentages of total purchase cost (>NT$600,000) in the current year:

- 7% for energy conservation or emerging/clean energy utilization equipments.
- 5% for energy conservation or emerging/clean energy utilization technologies.

If the profit-seeking enterprise income tax for the current year is not enough to be granted a tax deduction for investment, they may deduct the tax in the next 5 years for their profit-seeking enterprise income taxes.

Other than the above-mentioned regulation, the central government also provides preferential loans with low interest rates for encouraging the purchase of energy saving or emerging/clean energy equipments (e.g. cogeneration system) in the industrial sector under the authorization of Article 21 of SUI. In order to coordinate with the government policy, Chiao Tung Bank or Taiwan Business Bank will offer low-interest loans, which are less than 2-year regular interest of deposits in the post office plus 2.45 percent.

5. Environmental regulations and policies for encouraging and regulating cogeneration system

5.1. Basic Environment Act

In order to establish and integrate guiding principles for all related legislations, the law was first drawn up by the central competent authority (i.e. EPA) in 1988. Afterward, in response to the environmental changes and trend towards sustainable development, the EPA revised the law (draft) many times with deliberation. The Legislative Yuan finally passed this significant environmental law (Basic Environment Act, BEA) at the end of 2002 [17]. To ensure the attainment of the goal in environmental quality, the BEL instructs the Executive Yuan to establish a national sustainable development committee to serve as a decision-making and supervisory mechanism in implementing related environmental issues (Article 21). In fact, the Executive Yuan established the committee known as the Council for Sustainable Development (NCSD), in 1997. In the Article 21 of BEA, the provision also instructs the government to actively adopt measures to control carbon dioxide emissions and establish related plans to mitigate the greenhouse effect. Under the authorization of the Act, there are some related provisions concerning the concepts of energy saving, which were briefly described as follows:

1. To achieve the aim of sustainable development, an enterprise shall incorporate the concept of environmental protection into the proceeding activity at the planning stage. Based on the life cycle, an enterprise shall also promote cleaner production, prevent and reduce pollution, save resource, recycle reusable resource and use material and service that are beneficial to mitigation of environmental loading (Article 6).

2. To mitigate the greenhouse effect, all levels of central and local governments shall actively adopt measures to control carbon dioxide emissions and establish related plans (Article 21).
3. To pursue the reasonably efficient resource utilization and respond to the necessity of environmental protection, all levels of central and local governments shall take adequate measures including preference, promotion, assistance or compensation for the items such as research and development on energy-saving technology and installation of energy-saving product (Article 37).

5.2. Air Pollution Control Act

In Taiwan, the basic law governing and promoting air pollution control and prevention is the Air Pollution Control Act (APCA), which was initially passed in May 1975, recently amended in May 2005 [18]. The goal of this act is set to prevent and control air pollution, safeguard public health, protect against air quality deterioration and raise the living environment. Under the authorization of the Act, there is a related regulation (*Emission Standards of Air Pollutants for Power Utilities*) concerning emission standards of air pollutants from the stationary sources of cogeneration system, which are briefly described as follows:

1. According to the Provision 2 of the Standards, the power utilities are defined to include the boiler used for the cogeneration system. However, the power system from the waste incinerators was excluded from the Standards.
2. In the Provision 5 of the regulation, the exhaust vent gas from the boiler of cogeneration system shall comply with particulate pollutant, sulfur oxides (SO_x) and nitrogen oxides (NO_x), which were listed in Table 6. In view of the standards in Table 6, the emission standards of nitrogen oxides (NO_x) implemented from July 1, 2001 were effective for the stationary pollution sources set up before April 11, 1992. For example, the NO_x levels for using solid-type fuel will be reduced from the former levels of 300–350 ppm to 250–300 ppm. Clearly, the provision aims at pursuing clean fuels as a way to improve ambient air quality.

5.3. Environmental Impact Assessment Act

The preventative approach towards environmental protection and pollution prevention started in the end of 1980s in Taiwan. Obviously, the introduction of environmental impact assessment (EIA) could significantly strengthen the prevention and mitigation of adverse impacts at the early stage of development activities. The Article 5 of Environmental Impact Assessment Act (EIAA), first promulgated in December 1994 and recently revised in January 2003, authorizes the central competent authority (i.e. Environmental Protection Administration) to conduct EIA for the development activities that are likely to cause adverse impacts on the environment [19]. Further, a regulation (i.e. "Working Guidelines for Environmental Impact Assessment of Development Activities") promulgated by the central competent authority under the authorization of EIAA requires those prescribed development activities that EIA shall be conducted, including the construction/extension of cogeneration facilities. For example, EIA shall be conducted for

Table 6
Emission standards of air pollutants for power utilities in Taiwan

Air pollutant	Standard[a]
Particulate matter	
	Opacity: 20%[b] Standard by effluent rate is nearly calculated as follows: $C = 1860\ (3Q)^{-0.386}$ C: effluent limit (mg/Nm^3); Q: effluent rate (N m^3/min)
Sulfur oxides (as sulfur dioxide)	
	Gas fuel: 50 ppm Liquid fuel: 300 ppm Solid fuel: 300 ppm Mixed fuel: $C = 50\ Q_1 + 300\ Q_2 + 300\ Q_3$ C: effluent limit (ppm) Q_1, Q_2, Q_3: ratios of gas, liquid and solid fuels to total heat input, respectively
Nitrogen oxides (as nitrogen dioxide)	
	Gas fuel: 120 ppm ($Q > 2500$ N m^3/min) 135 ppm (Q 500–2500 N m^3/min) 150 ppm ($Q < 500$ N m^3/min) Liquid fuel: 200 ppm ($Q > 2500$ N m^3/min) 220 ppm (Q 500–2500 N m^3/min) 250 ppm ($Q < 500$ N m^3/min) Solid fuel: 300 ppm ($Q > 2500$ N m^3/min; facility set up before April 11, 1992) 250 ppm ($Q > 2500$ N m^3/min; facility set up after April 12, 1992) 325 ppm (Q 500–2500 N m^3/min; facility set up before April 11, 1992) 280 ppm (Q 500–2500 N m^3/min; facility set up before April 12, 1992) 350 ppm ($Q < 500$ N m^3/min; facility set up before April 11, 1992) 300 ppm ($Q < 500$ N m^3/min; facility set up before April 12, 1992) Mixed fuel: $C = L_1\ Q_1 + L_2\ Q_2 + L_3\ Q_3$ C: effluent limit (ppm) L_1, L_2, L_3: effluent limits in the uses of gas, liquid and solid fuels, respectively Q_1, Q_2, Q_3: ratios of gas, liquid and solid fuels to total heat input, respectively

[a]Concentration calculation of air pollutant in the stack gas must be based on 273 K, 1 atm and dry volume of undiluted effluent. Also, 10% O_2 (oxygen content) is referred as correction baseline.
[b]Legislated by visual determination.

the cogeneration facilities, which are located in one of the following sites or comply with the power capacity or accumulative power capacity requests:

- Location in national parks.
- Location in wildlife protection areas or important wildlife habitats.
- Location in land for city use and the construction of cogeneration system using gas fuel over 100,000 kW (power capacity) or using oil, coal or other fuels over 50,000 kW (power capacity).

- Location in land for city use and the extension of cogeneration system using gas fuel over 100,000 kW (accumulative power capacity) or using oil, coal or other fuels over 50,000 kW (accumulative power capacity).
- Location in land for non-city use and the construction of cogeneration system using gas fuel over 200,000 kW (power capacity) or using oil, coal or other fuels over 100,000 kW (power capacity).
- Location in land for non-city use and the extension of cogeneration system using gas fuel over 100,000 kW (accumulative power capacity) or using oil, coal or other fuels over 50,000 kW (accumulative power capacity).

6. Environmental benefits from cogeneration system

As described above, the environmental benefits from cogeneration system are lower GHGs emissions to the environment, in particular of carbon dioxide (CO_2) and nitrous oxide (N_2O). According to the data in Table 2, the portions of fuel type used in cogeneration systems (see the description in Section 2.3) and International Panel on Climate Change (IPCC) recommended methodology [20], the environmental benefits from electricity supply by all installed cogeneration systems in 2004 are quantitatively analyzed as compared to conventional power systems (its thermal efficiency was assumed to be about 35%):

- CO_2

$$\begin{aligned} CO_2 \text{ equivalent reduction (metric ton, MT)} &= 4.258 \times 10^{13}\,\mathrm{W-h} \times 3600\,\mathrm{s/h} \\ &\times 1\,\mathrm{J/W\,s} \div 35\% \times 10^{-12}\,\mathrm{TJ/J} \\ &\times [(67\% \times 20\,\mathrm{MT\,C/TJ}) \\ &+ (17\% \times 26\,\mathrm{MT\,C/TJ}) \\ &+ (11\% \times 30\,\mathrm{MT\,C/TJ}) \\ &+ (4\% \times 15\,\mathrm{MT\,C/TJ})] \\ &\times 44/12 = 3.488 \times 10^{7}\,\mathrm{MT}. \end{aligned}$$

- N_2O

$$\begin{aligned} N_2O \text{ equivalent reduction (metric ton, MT)} &= 4.258 \times 10^{13}\,\mathrm{W-h} \times 3600\,\mathrm{s/h} \\ &\times 1\,\mathrm{J/W\,s} \div 35\% \times 10^{-12}\,\mathrm{TJ/J} \\ &\times [(67\% \times 1.4\,\mathrm{kg/TJ}) \\ &+ (17\% \times 0.6\,\mathrm{kg/TJ}) \\ &+ (11\% \times 4.0\,\mathrm{kg/TJ}) \\ &+ (4\% \times 0.1\,\mathrm{kg/TJ})] \\ &\times 10^{-3}\,\mathrm{MT/kg} \div 35\% = 650\,\mathrm{MT}. \end{aligned}$$

7. Conclusions and recommendations

Since the early 1980s, electricity generation in Taiwan was moving toward liberalization and deregulation in response to the trend of global economic and industrial developments.

One of the significant milestones in the reform of the electricity industry in Taiwan could be said to have been implemented in 1988 when the central competent authority (i.e. MOEA) first promulgated the "Promotion Measures for Cogeneration System". Under the government policy, industrial plants operated by private corporations have been encouraged to install their cogeneration systems for the purpose of selling their surplus electric power to Taipower. By the end of 2005, total installed capacity of cogeneration systems reached 7046 MW, which accounted for around 17% of total electricity supply in Taiwan. The growth rate of total installed capacity of cogeneration system, however, seemed to reach a plateau in recent years, mainly due to the decreasing trend in domestic investments by the industrial sector.

From the viewpoints of energy conservation and environmental benefits, cogeneration system can be considered as one of sustainable energies. Under the policy encouragement and financial subsidies, it is undoubtedly expected that the Energy Management Law and Electricity Act would be further amended so as to drive the installations of more cogeneration systems in the industrial sector and other sectors in the near future. To encourage the investment in cogeneration system as an energy-efficiency improvement and a measure for the reduction of greenhouse gases emissions and also achieve the government goal (i.e. total installed capacity reached 1000 MW) in 2020, the following measures are recommended and enhanced:

- Increase the subsidies to install cogeneration system under the support of special funds (e.g. "Air Pollution Control Fee") because of its environmental benefits from the reduction of greenhouse gases emissions.
- Raise the current operating standards (i.e. 20% and 52% for the levels of effective thermal ratio and total thermal efficiency, respectively) to be no less than the cost-effective and technology-available levels (for example, 25% and 60%, respectively).
- Give preferential price for purchasing surplus electricity to encourage the use of LNG in the cogeneration system because coal is the dominant fuel in the industrial sector.
- Demonstrate new cogeneration technologies (e.g. micro-turbine, fuel cell and Stirling engine) appeared on the market for the purpose of broadening a wide variety of applications to residential and commercial sectors.
- Promote the implementation of environmental accounting or green accounting and combine "green" costs (e.g. carbon or energy tax) with the accounting system of enterprise or business.
- Deregulate the electric power industry in Taiwan by the amendments of Electricity Act to upgrade the operation performances of the existing cogeneration systems because of the competitive pressure from new entrant generators.

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